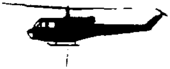
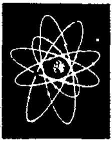
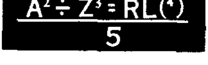
MODELS and system effectiveness

Robert R. Hare, Jr.







THE military planner at every level of activity has always found that the resources available for his program are limited. He is continually faced with the problem of deciding how these resources should be allocated in order to assure that the mission of his particular activity is accomplished.

In the course of solving this problem, the planner spends much of his time making decisions with regard to individual systems. He may consider how an existing system, such as a communications network or an infantry battalion, might be modified to improve its performance, and then decide whether such modification is desirable from the standpoint of cost. He may have to decide when an existing system should be eliminated or replaced, or he may have to choose between competing systems that have been proposed to fill a particular requirement.

In order to have a rational basis for making such decisions, the planner must obtain rather complete estimates of system effectiveness as it re-

lates to military needs, and he must determine the costs involved in terms of available resources.

In recent years, operations research and systems analysis have proved to be of considerable value as sources of information and comparison regarding the operation, effectiveness, and cost of alternative military systems. As a result, the military planner has come to rely more and more on the systems and operations analyst to provide him with the necessary information on which to base his decisions.

Operations research and systems analysis are not specific techniques, or even collections of techniques. Instead, they are essentially the application of the scientific method to the study of systems and their operations, just as physics is an application of the scientific method to the study of matter and energy.

Methods of Solution

A number of techniques are used occasionally by the analyst—game theory, information theory, queuing theory, linear and dynamic programing, input-output analysis, and system simulation. But the operations analyst does not distort a problem to fit a particular method of solution. On the contrary, he uses whatever methods he can invent, beg, borrow, or steal to solve the particular problem at hand.

Robert R. Hare, Jr., is with Operations Research, Incorporated, and until recently was stationed with the Scientific Support Group, US Army Combat Developments Command Institute of Advanced Studies, Carlisle Barracks, Pennsylvania. He holds a Master's degree in Mathematics from DePauw University, Greencastle, Indiana; was Chief of the Mathematics Analysis Section, Data Reduction Branch, Air Force Missile Test Center; and has served with Johns Hopkins University Operations Research Office.

Determining costs of a system and its elements for comparative purposes is difficult. This half of cost effectiveness has been dealt with by Professor John J. Clark, Major General Clifton F. von Kann, and Colonel James H. Hayes in previous issues of the *Military Review*.* Measurement of effectiveness may be equally, if not more, difficult, and sometimes seemingly impossible—yet definitive systems analysis, operations research, and cost effectiveness studies cannot be complete without this part of the equation.

Estimating Problems

The problems of estimating the effectiveness of a complex system, or of modifying it in response to technological and economic change, have become increasingly difficult in today's military operations. Associated with these problems is the need to understand the interrelationships among system elements in order to predict the behavior of the system and to facilitate its control by the commander.

It has become apparent in recent years that past operating experience alone is no longer an adequate means for obtaining this understanding, particularly where it is necessary to project the effects of new conditions on a system. Such experience usually represents only a small sample of the possible ways in which the system might be operated.

In certain instances, measurement and analysis of past operations alone

* John J. Clark, "The Economics of Systems Analysis," *Military Review*, April 1964, pp 25-31.
Major General Clifton F. von Kann, "The Army and Cost/Effectiveness," *Military Review*, September 1964, pp 3-11.
Colonel James H. Hayes, "Basic Concepts of Systems Analysis," *Military Review*, April 1965, pp 4-13.

may reveal simple cause-and-effect relationships from which predictions can be made regarding the consequences of alternative modes of operation. For most modern systems, though, such predictions cannot be made until after a substantial amount of additional information has been collected.

'Real-System' Experiments

One possible way of getting additional information about a system is by carrying out "real-system" experiments. This concept proposes deliberate experimentation with the operating system itself, or a large segment of it. Its objective is that of any experiment—to gain information not otherwise available or to test a theory which, if valid, has broader practical applications.

Although real-system experimentation has been, and continues to be, carried out by both industry and the Armed Forces, it has certain serious limitations. This approach cannot be used in many instances because of high cost in money and time, because of unacceptable consequences in the event of failure, or because the approach may be downright infeasible. There is, for example, only a limited amount of useful experimentation that can be carried out on certain systems related to civil defense or to tactical operations on a battlefield, since such systems become fully operational only in times of emergency or war.

Perhaps the most serious limitation of real-system experimentation is that it cannot be conducted on proposed future systems that are still only tentative concepts or preliminary designs. This is an area in which improved understanding is especially needed, and which is becoming increasingly important as the rate and cost of technological change increases.

The limitations of operating experience and of real-system experimentation have caused systems analysts to look for other ways of obtaining the information they require, and their search has led them to the extensive use of system models. The analysis of models, particularly those that are basically mathematical in design, has assumed a vital role as an aid to management in its decisions concerning the development, improvement, and operation of major systems.

Types of Models

A model can be defined as a useful, simplified representation of the essentially important aspects of a real object or situation. A model of a system can be a picture, a mechanical or electrical device, a set of mathematical equations, or anything else having characteristics representative of those that are fundamental to the system.

Ordinarily, a model will be much simpler than the system it represents, since an important goal of model design is to omit all detail of the original system that is unimportant to the study of the system's operation. The purpose of this is to reduce as much as possible the effort required to analyze the interrelationships that exist among the different elements of the model.

If the model has been well designed, an analysis should then yield information about the corresponding interrelationships among elements of the original system. In other words, a good model will be designed so that what happens in the model accurately reflects the important things that would happen in the system to which it corresponds.

An obvious question at this point is: How do we know what is impor-

tant and what is not in a system? There is no clear-cut answer to this question. Some elements of a system will be of obvious importance; others not so obvious.

Wherever a question arises as to the significance of a system element, it should be represented in the model, although it may be omitted later if subsequent analysis shows that the questionable element is not important. On the whole, the design of an adequate model is something of an art, and requires that the designer know the system with which he is concerned.

When a model is used in the analysis of a system, the analyst is generally interested in determining quantitative relationships which can then be applied to the system. Therefore, the model should be constructed so that there is a known correspondence between model values and system values. Generally, one is the same or proportional to the other. If a map is a visual model of a certain piece of terrain, for example, distances on the map are proportional to distances on the terrain, and corresponding angles have the same value.

US Army

In recent years, operations research and systems analysis have proved to be of considerable value as means of obtaining information about and comparing the operation and effectiveness of military systems such as the *Mauler*

Models are ordinarily classified as visual, analogue, or symbolic. Of course, these classifications are not rigid, and several may apply to a given model at the same time. Navigation charts and house floor plans are examples of visual models; both are much simpler than the things they

represent, and contain only significant elements of the original and none of the unessential detail.

At the same time, they are useful —the chart helps the mariner steer from one buoy to the next, even though he is often unable to see more than one buoy at a time. The floor plan helps the architect detect and correct faults in the house layout before starting construction.

A common analogue model is the electrical network which is used to represent mechanical, waterflow, and many other kinds of systems.

The type of model that has been especially valuable in the study of complex systems is the symbolic model which is composed of mathematical and logical relationships. An example of such a model is one used in the engineering design of bridges. It is made up of a number of theoretical and empirical relationships involving Hooke's law, Young's modulus, the mechanics of materials, stress analysis, and vibration analysis. With the aid of these mathematical representations, bridge structures can be designed quickly and cheaply.

Another symbolic model is computer simulation, which has made possible the analysis of complex systems that could not ordinarily be analyzed prior to the development of high-speed digital computers.

The process of constructing a model, in itself, will tend to give a better understanding of the system and how it functions, and information provided by the model can be used to improve the system. System improvements may include changes in equipment and personnel, in operating doctrine and procedures, in command and control procedures, and changes in organization. Model analysis, unlike real-system experimentation, can be applied to proposed systems as well as those that already exist.

Two practical observations must be made regarding the use of system models. The usefulness of any model will be limited by the amount and quality of basic operational data available for input. The model designer, however, should ordinarily be able to get most of this data from existing records and measurements of the system's past operation, and by working closely with system management and operating personnel.

If information about the value of a particular factor in the system is not available from these sources, however, a reasonable range of values may be estimated, and the model can be used to examine system operation for this range. If it is found by this means that the performance of the system is strongly affected by the value of the missing factor, then some experimentation with system components may be required to obtain the value.

The second observation is that model analysis cannot be a complete substitute for full-scale trial of a system. Models can help to organize and analyze experience data for the purpose of drawing certain conclusions, but intangible factors which a model cannot take into account will often affect system operation significantly. Military planners, therefore, must know the limitations of the models they employ, and must use their experience and good judgment to interpret model results in the light of intangible factors.